Document made available under the Patent Cooperation Treaty (PCT)

International application number: PCT/US04/030116

International filing date: 14 September 2004 (14.09.2004)

Document type: Certified copy of priority document

Document details: Country/Office: US
Number: 60/537,868
Filing date: 20 January 2004 (20.01.2004)

Date of receipt at the International Bureau: 27 June 2005 (27.06.2005)

Remark: Priority document submitted or transmitted to the International Bureau in compliance with Rule 17.1(a) or (b)

World Intellectual Property Organization (WIPO) - Geneva, Switzerland
Organisation Mondiale de la Propriété Intellectuelle (OMPI) - Genève, Suisse

1334671

THE UNITED STATES OF AMERICA

TO ALL TO WHOM THESE PRESENTS SHALL COME:

UNITED STATES DEPARTMENT OF COMMERCE

United States Patent and Trademark Office

June 16, 2005

THIS IS TO CERTIFY THAT ANNEXED HERETO IS A TRUE COPY FROM THE RECORDS OF THE UNITED STATES PATENT AND TRADEMARK OFFICE OF THOSE PAPERS OF THE BELOW IDENTIFIED PATENT APPLICATION THAT MET THE REQUIREMENTS TO BE GRANTED A FILING DATE.

APPLICATION NUMBER: ***60/537,868***
FILING DATE: ***January 20, 2004***
RELATED PCT APPLICATION NUMBER: ***PCT/US04/30116***

UNITED STATES PATENT AND TRADEMARK OFFICE
DEPARTMENT OF COMMERCE

Certified by

Jon W. Dudas

Under Secretary of Commerce
for Intellectual Property
and Director of the United States
Patent and Trademark Office

16179 U.S. PTO 012004

PTO/SB/16 (01-04)
Approved for use through 07/31/2006. OMB 0651-0032
U.S. Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE

PROVISIONAL APPLICATION FOR PATENT COVER SHEET

This is a request for filing a PROVISIONAL APPLICATION FOR PATENT under 37 CFR 1.53(c).

Express Mail Label No. EL 974386878 US

031431 U.S. PTO 60/537868 012004

INVENTOR(S)		
Given Name (first and middle [if any])	Family Name or Surname	Residence (City and either State or Foreign Country)
Paul D.	Zemany	Amherst, NH
Eldon M.	Sutphin	Merrimack, NH

Additional inventors are being named on the ____________ *separately numbered sheets attached hereto*

TITLE OF THE INVENTION (500 characters max)

Methods And Apparatus For Urban Through Wall Sensing

Direct all correspondence to: **CORRESPONDENCE ADDRESS**

☑ Customer Number: 22500

OR

☐ Firm or Individual Name					
Address					
Address					
City		State		Zip	
Country		Telephone		Fax	

ENCLOSED APPLICATION PARTS ***(check all that apply)***

☑ Specification *Number of Pages* 15 ☐ CD(s), Number ____________

☑ Drawing(s) *Number of Sheets* 2 ☐ Other (specify) ____________

☐ Application Data Sheet. See 37 CFR 1.76

METHOD OF PAYMENT OF FILING FEES FOR THIS PROVISIONAL APPLICATION FOR PATENT

☐ Applicant claims small entity status. See 37 CFR 1.27.

☐ A check or money order is enclosed to cover the filing fees.

☑ The Director is herby authorized to charge filing fees or credit any overpayment to Deposit Account Number: 190130

☐ Payment by credit card. Form PTO-2038 is attached.

FILING FEE Amount ($): 160.00

The invention was made by an agency of the United States Government or under a contract with an agency of the United States Government.

☐ No.

☑ Yes, the name of the U.S. Government agency and the Government contract number are: DARPA and NIJ N39998-97-C-5216 and F30602-02-C-0018

~~[Page 1 of 2]~~

Respectfully submitted,

SIGNATURE Daniel J. Long

TYPED or PRINTED NAME Daniel J. Long

TELEPHONE 603-885-2643

Date 1/20/04

REGISTRATION NO. 29,404 *(if appropriate)*

Docket Number: 20040005 PRO

USE ONLY FOR FILING A PROVISIONAL APPLICATION FOR PATENT

EXPRESS MAIL CERTIFICATE EL 974386878 US

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Application of: ZEMANY, et al.

Filed: Herein Atty. Dkt. No: 20040005 PRO

For: METHODS AND APPARATUS FOR URBAN THROUGH WALL SENSING

CERTIFICATE OF MAILING 37 CFR 1.10: I certify that this correspondence is being deposited on the below date with the U.S. Postal Service with sufficient postage as EXPRESS MAIL addressed to: US Patent and Trademark Office, 2011 South Clark Place, Customer Window, Mail Stop Provisional Application, Crystal Plaza Two, Lobby, Room 1B03, Arlington, VA 22202

Date: 1-20.04 Gloria Abbasciano

Gloria Abbasciano

Dear Honorable Commissioner:

LETTER OF TRANSMITTAL

Submitted herewith is a Provisional Patent Application consisting of 1 pages of cover sheet, 15 pages of specification and claims, 2 sheets of drawings.

[X Invention was made by an agency of the United States Government or under a contract with an agency of the United States Government.

DEPOSIT ACCOUNT **190130** AUTHORIZATION – The Office is hereby authorized to charge the required fee, and any deficiency or credit any overpayment in the fees to the above deposit account, owned by BAE SYSTEMS Information and Electronic Systems Integration Inc.

Respectfully submitted,

Daniel J. Long

Daniel J. Long, Reg. No. 29,404

USPTO Cus. No. 22500
BAE Systems
PO Box 868, NHQ01-719
Nashua, NH 03061-0868
Tel 603.885.2643
Fax 603.885.2167

METHODS AND APPARATUS FOR URBAN THROUGH WALL SENSING

Statement of Government Interest

Various inventions described herein were made under Contract Nos. N39998-97-C-5216 and F30602-02-C-0018 with the Government of the United States of America and such inventions may be manufactured and used by and for the Government of the United States of America for Governmental purposes without the payment of any royalties thereon or therefor.

Background of the Invention

1. Field of the Invention

The present invention relates to sensors and more particularly to methods and apparatus for sensing through wall.

2. Brief Description of Prior Developments

Through wall sensing can be used in Military Operations in Urban Terrain (MOUT), homeland security, and law enforcement. The need to sense behind walls is clear. The details of the mission and types of walls or obstructions dictate the design of the through wall sensors. Several types of through wall sensors (TBS) were tested. Testing has included lab tests to operational field testing. Results of these tests showed that no one approach can meet the user's TWS requirements. Instead, one must select a frequency range and waveform as well as the size and power that meets the user's mission needs.

Summary of Invention

The present invention includes a method for generating an image from a plurality of IR impulses comprising the steps of selecting a pixel location (i,j); calculating the distance that the RF travels Rij from to the pixel and to the receiver and back to the antenna; evaluating the impulse response Rij. This value is denoted I(Rij); and accumulating the value into pixel (i,j). Pij=Pij+I(Rij)

Brief Description of the Drawings

The present invention is further described with reference to the accompanying drawings wherein:

Figure 1 is a schematic drawing illustrating the near field processing method of the present invention;

Figure 2 shows an image of a human behind a wall with background subtracted made according to the method of the present invention;

Figure 3 is a schematic drawing showing CW motion detector radar used in the present invention;

Figure 4 is a 900 MHz radar with Yagi; and

Figure 5 is a flat panel antenna used in the present invention.

Detailed Description of the Preferred Embodiment

1. Near Field Hand Held SAR (HHSAR)

Tests were performed to evaluate the feasibility of a "hand held" imaging radar. Since the best wall penetration frequencies for dense walls are below 3 GHz, a synthetic

aperture radar (SAR) approach was investigated. An array would be too large for a hand held or portable unit. By using SAR, the size of the antenna can still be small. The approach was based on an "unconventional" synthetic aperture radar (SAR) approach. In this approach, a stepped frequency sweep from 1 to 3 Ghz was used. This allows an impulse response to be generated. With only one impulse response measurement using a broad beam antenna, one can only obtain information about the range profile of all structures contained in the beam. No information about the angular structure of the scene is provided. To obtain cross range information, a narrow beam must be formed. In conventional SAR the locations are uniformly spaced and the objects are far away and the beam is formed using FFT processing. This simplifies the processing, but it is not critical to SAR imaging. There is no need to have evenly spaced points or to be far from the scene. In the case of the HHSAR, the measurement locations are not uniformly spaced and the target is close. The non-uniformity eliminates the use of FFT processing for aperture generation. The closeness of the target also requires focusing. However, the basic concept is still the same. When viewed from the time domain, the processing required for non-uniform spacing of measurements and close targets is easier to understand.

Figure 1 shows the image formation processing from a set impulse responses measured at multiple locations. Figure 1 shows a grid of pixels that form the image as well as the locations of the of the radar antenna. A frequency sweep is done for each location of the antenna. Each frequency sweep produces a range profile (time domain impulse response I(R)). The image generation processing consists of the following steps for each measured impulse response I(R):

(1) Select a pixel location (i,j).

(2) Calculate the distance that the RF travels Rij from to the pixel and to the receiver and back to the antenna.

(3) Evaluate the impulse response at Rij. This value is denoted I(Rij).

(4) Accumulate the value into pixel (i,j). Pij=Pij+I(Rij)

Steps 1-4 are done for all pixels (i=1,N and j=1,M) in the image. Note that in step 4, each pixel is a sum of all the impulse response functions taken from each location. Thus the above process accumulates results for multiple a set of impulse responses measured from a set of receiver and/or transmitter locations. This process forming an image is referred to as Near Field Synthetic Aperture Radar (SAR). Note that, in most cases, the descriptions of SAR are in the frequency domain because the spacing between measurements is uniform. However, the essential feature of SAR is that interference effects produced over multiple locations are used to form beams to obtain cross range information. In essence, SAR obtains the effect of a large directional antenna by measurements at multiple locations. The processing described above is general in that it applies to nonuniform spacing and near field measurements.

2. Near Field SAR Results

A test was done to see if the near field SAR approach could detect people behind a cinderblock wall. The antenna was moved along a 5 foot line parallel to the wall. Frequency sweep data was collected for 60 points spaced along the line. The person was standing behind the wall in a room that had metal desks and chairs. The room also had metal heating ducts in the ceiling. The processed data showed that clutter is a source of difficulty for the HHSAR because room had many human size conducting objects. It was

not possible to identify the features in the pixel map as human or other objects. A clutter map subtraction approach was used to detect the person behind the wall. The approach involves an initial measurement set to generate a clutter map of the room. Then a second measurement set with a person standing in the room was made. The clutter map is subtracted (after a registration process) to from the new image. The resulting image will highlight any changes. Thus, the person will be highlighted. Figure 2 shows the results of clutter map subtraction.

Note that this approach is limited because at least two measurement sets must be collected. Each measurement set involves a set of 60 frequency sweeps taken over a 5 foot baseline. Each measurement set is used to form an image and the two images are differenced. This resulting difference image shows any changes that occur. In the case shown in Figure 2, the change was due to a person being positioned behind the wall.

Other tests were done to evaluate the approach. In particular, tests were done to evaluate the required positioning accuracy. It was found that the quality of the image degraded significantly if the RMS position error exceeded 1 inch. A means of producing a set of relative position to an accuracy better that about 1 inch over a 5 foot baseline is needed. Note that in the imaging tests this was done with the antenna mounted on a track that had a position encoder. For a hand held portable unit, an inertial sensor might be used. However, it would be difficult to obtain the needed positioning accuracy. Other sensors would be needed (laser rang finder) to provide the needed positioning accuracy.

Tests of the HHSAR were also were conducted for non-uniform walls as well as dense walls (concrete). It was found non-uniform walls caused distortions that prevented the formation of images. This was expected since the wall material has a fairly high

dielectric constant (over 5). Dense walls also limit the image quality since they are dispersive. The transmission loss varies by over 20 dB over the 1 to 3 Ghz range. This dispersion was found to degrade the range resolution.

For a frequency swept approach, we found that is possible to obtain good range measurements by correcting for this dispersion. A weighting that accounted for the frequency dependent loss was able to improve the range measurements. However, in a practical system. such a correction would require measurement of the wall. Possibly an adaptive approach that adjusts the correction to sharpen the impulse response from objects behind the wall could be developed. Note that this dispersion correction is not possible for a pulsed system. For a pulsed system, the wall dispersion would broaden the pulse.

A practical HHSAR would require the user to be close to the building or wall. The system would be moved over a baseline of about 5 feet. Multiple passes would be required. An alternative to this would be an array. This array would be 5 feet long. The same near field processing approach could be applied.

3. Motion Detection Radar

The work done in relation to this invention showed that clutter, wall dispersion, and wall non-uniformity were significant challenges. In addition, SAR approaches require a means of precise position measurement. Further development work is required before a practical system can be built.

To develop a simple and low cost approach, a single frequency CW radar was tested. A simple motion detection radar does not require position estimates or complex

processing. Units that used frequencies ranging from 900 MHZ to 24 GHz were tested in the laboratory as well as in a government owned MOUT facility. It was found that there were operational advantages and disadvantages associated with the frequency choice. The low frequency (900 MHz) was useful for dense walls and situations that require longer standoff. The higher frequencies were more useful when the mission requires hand held operation inside buildings. long standoff distances The following sections describe test results as well as the system

3.1 TWS CW Motion Detection Radar

The basic principle behind the TWS Radar detection is shown in Figure 3. As shown in the figure, the CW radar contains a RF source, power divider, mixer, antenna, circulator, A/D, and a processor. The RF source transmits a signal via the antenna. This signal is reflected back to the antenna by all objects in the antenna pattern. The circulator allows the reflected RF antenna that is used to transmit. The mixer combines the reflected RF with a sample of the transmitted RF. If an object that is reflecting RF back to the radar moves, the relative phase and the transmitted RF will change. This will result in a change in the mixer output. The A/D and processor monitors the mixer output and detects changes that are caused by moving objects. If the change is above the measured background, the processor will generate a detection report.

All of the CW motion detector radars work as described above. Units were built for different frequencies (900 MHz, 2.4 GHz, 10 GHz, and 24 GHz) for testing and demonstration purposes. Table 1 summarizes the different frequency ranges.

Table 1.

Frequency	Adobe Concrete	Brick Cinder-block	Wood Drywall	Cloth	Antenna Dimension
100-300 MHz	X	X	X	X	10 meters
300-1000 MHz	X	X	X	X	3 meters
1-3 GHz	Limited	X	X	X	1 meter
3-10 GHz		Limited	X	X	0.3 meter
10-30 GHz			X	X	0.1 meter
30-100 GHz			Limited	X	0.03 meter

The table shows an antenna dimension that is based on 10 times the wavelength. This is required to form a narrow beam.

The electronics for all the units is small and can easily be put into a small package (cell phone size). In addition, the units can be battery powered. A small 9 volt battery was used. The antenna drives the unit size if the frequency is below 3 GHz. Figure 4 shows the 900 MHz unit with a Yagi antenna. The tradeoff in frequency involves wall penetration, antenna size, and beam resolution. For frequencies above 3 GHz, small antennas can obtain narrow beams. However, the wall penetration ability is limited. Low frequencies penetrate better, but require large antennas. A frequency of 900 MHz was selected for dense through wall testing because it the antenna can still be portable. For less dense interior walls, a higher frequency (2.4 GHz) is more suitable.

3.2 900 MHz Radar MOUT Tests

To test the 900 MHz radar, the u.s. Army's Dismounted Battlespace Battle Lab (DBBL) conducted a Limited Objective Experiment (LOE) of the 900 MHz radar. The purpose of this LOE was to measure the performance in an urban environment under operational conditions. The objective of the experiment was for the soldier operators to

use the radar sensor to gather information on a room/building in which they would be conducting a forcible entry. This experiment examined the following Measures of Performance:

- Performance through a representative sample of wall construction materials.
- Ability to indicate target persons location.
- Ability to detect persons in subterranean sewer tunnels.
- Interference effects of various types of RF transmissions and electrical appliances.
- Maximum standoff distances.
- Ability to discriminate target type (threat or non-threat, human or animal).
- Operation while mounted in a tactical vehicle.

The tests evaluated standoff range, detection probability through various wall types, effects of clutter, potential sources of RF interference, and effects of building geometry.

The radar used in these tests was monitored by listening to an audio tone. This tone was shifted using the mixer output. Thus, any motion in the radar's beam generated an audible shift in the tone.

3.2.1 Standoff Range Test

The stand off test showed that humans inside brick buildings could be detected from standoff ranges of up to 100 feet. As standoff distance increases, the less likely it is to pinpoint the room or even the building where sensed personnel are located. There is no function of this system that shows detection location. From a sixty-foot standoff, without any basis for determining location, operators could only guess. On the other

hand, with the antenna placed near the wall, the operator has a basis for determining the detection location (other side of the wall). Exacerbating the problem is the fact that movement may be detected through two or three walls, encompassing targets several rooms away from the one being sensed.

3.2.2 Wall Penetration Tests

Tests were done to evaluate detection through different wall types at a 10 foot standoff range In these tests, the radar system had an accuracy (90% average) in correctly detecting the presence or absence of moving personnel behind walls in a building. Information provided from this detection is limited to a simple yes or no. No information on location was provided by the radar. Operators cannot distinguish between a person and an animal. The walls tested were: Stucco, Brick, Reinforced Concrete, and Wood Frame with Vinyl Siding. For each wall, a total of 30 trials were conducted. One half of the trials consisted of an occupied room, and the remaining half consisted of an empty room. Results are shown below.

Table 2.

	Correct	Wrong	Occupied	Unoccupied
Stucco Wall	26	4	15/15	11/15
Brick Wall	28	2	15/15	13/15
Concrete Wall	27	3	15/15	12/15
Wood Wall	27	3	15/15	12/15

In all cases the soldiers called occupied rooms correctly 15 out of 15 times. Errors occurred in falsely calling empty rooms occupied (false alarms).

The wood frame w/vinyl siding wall completely blocked the radar system. This was due to the metal foil backed insulation. The radar was able to detect the targets moving past the wooden entry door.

3.2.3 Interference Tests

No interference occurred when operated in close proximity to the electrical wiring. Cell phones that operate around the same frequency range (900 MHz) as the 900 MHz radar caused no interference. Little interference was noted with the presence of metal stoves, refrigerators, pots and pans, etc. in the restaurant kitchen area as long as the target person remained upright and moving.

3.2.4 Through Floor Detection

From the ground floor of a multi-story building, the antenna was aimed upward to sense personnel on floors above. Movement was detected to the second and third floors. Movement was not on the fourth floor. The operator could not determine on which floor the target was located.

3.2.5 Vehicle Mounted Performance

For mounted operation, it was found that the idling engine vibration caused the signal to modulate. However, it was a steady rhythm that could be consciously filtered out once one became used to it. After that, sensing from the vehicle was just as accurate as ground mounted. The vehicle must not be moving.

3.2.6 Underground detection

Operators could not conclusively identify personnel moving through the sewer tunnels below the street.

3.2.7 Operational Restrictions

Friendly personnel moving behind and to the sides of the antenna may be detected up to 20 feet away, giving a nuisance reading.

The antenna must remain motionless while sensing. This was best done by mounting it on the camera tripod. A Soldier trying to hand hold the device has to be very still and hands held steady. It was noted that at one point a stiff breeze had developed that caused the antenna to oscillate. This caused nuisance readings.

4. CONCLUSIONS

The tests done in the MOUT facility provided valuable feedback for future development of urban through wall sensors. In particular, we identified ways to improve the system. One problem area was related to generation of false alarms caused by user motion in the back lobe of the antenna. To address this problem a flat panel antenna was developed. This antenna consists of 4 dipoles arranged over a ground plane. The antenna (shown in Figure 5) is a 20" by 20" square panel and the 900 MHz radar can be built in. It has a gain of 13 dB. The back lobe is significantly reduced compared to the yagi.

The 900 MHz radar unit was useful for missions that require stand off and for dense walls. However, for interior through wall sensing, the antenna was cumbersome. Part of this problem can be addressed by using the new panel antenna. A higher frequency (2.4 or even 24 GHz) could be used to provide a smaller beam width in a hand held unit. Tests of the 2.4 and 24 GHz units shows that they can be effective for less dense interior walls.

While the present invention has been described in connection with the preferred embodiments of the various figures, it is to be understood that other similar embodiments may be used or modifications and additions may be made to the described embodiment for performing the same function of the present invention without deviating therefrom. Therefore, the present invention should not be limited to any single embodiment, but rather construed in breadth and scope in accordance with the recitation of the appended claims.

Claims

What is claimed is:

1. A method for generating an image from a plurality of RF impulses comprising the steps of:

   (a) selecting a pixel location (i,j);

   (b) calculating the distance that the impulses travels Rij from to the pixel and to the receiver and back to the antenna;

   (c) evaluating the impulse response Rij, which value is denoted I(Rij); and

   (d) accumulating the value into pixel (i,j). Pij=Pij+I(Rij)

Abstract

Methods and apparatus for urban through wall sensing using RF. Such methods and apparatus use a wide range of frequencies from 900 MHz to 24 GHz as well as different modulation types. Approaches range from simple CW Doppler to a near field SAR. Considerations include physical limitations such as wall penetration as well as operational approaches.

Drawings

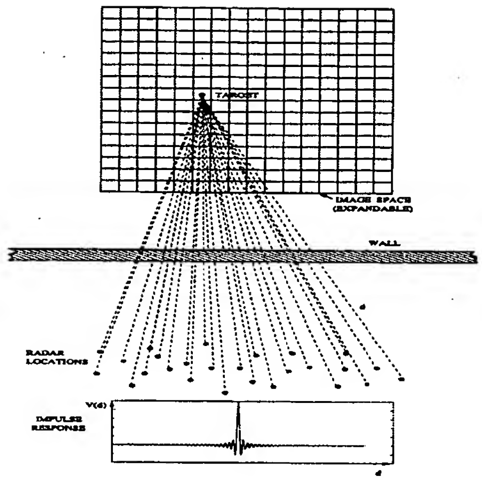

Figure 1

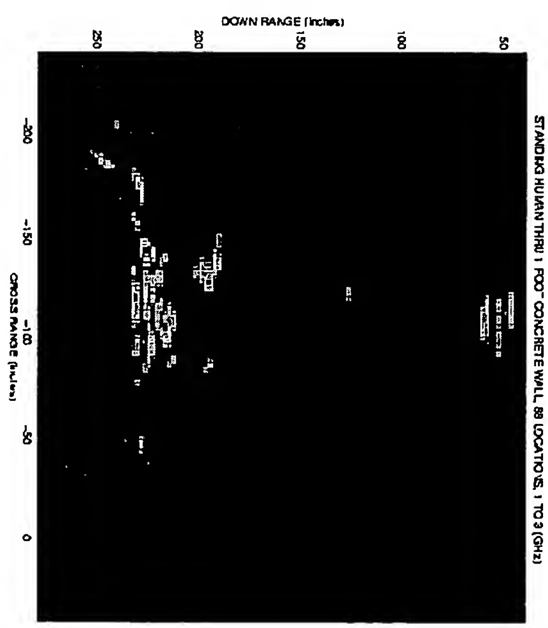

Figure 2

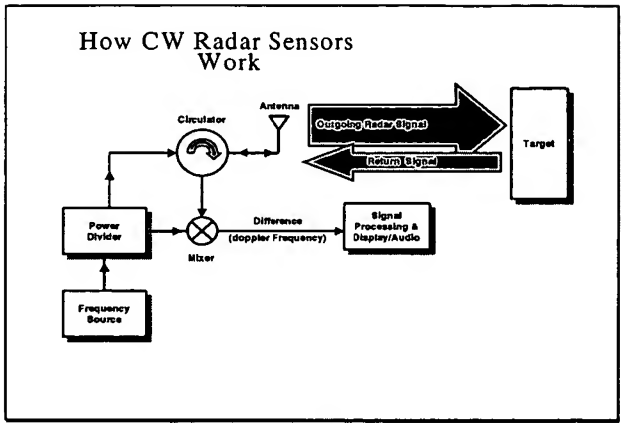

Figure 3

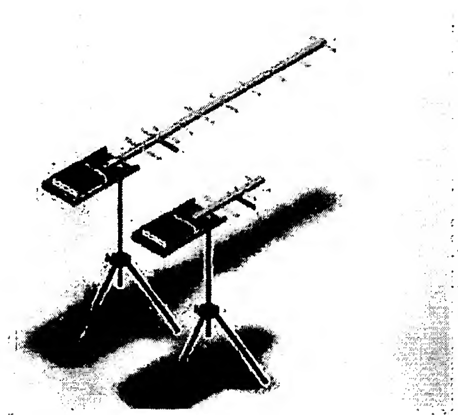

Figure 4

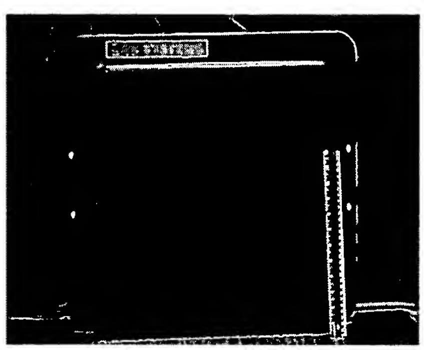

Figure 5